

F06296+5743 : A Very Massive Starburst ?

J.H.Huang^{1,3}, Q.S. Gu^{1,3}, H.J. Su^{2,3}, and Z.H. Shang^{2,3}

¹ Astronomy Department, Nanking University, Nanking, China

² Purple Mountain Observatory, Nanking, China

³ United Lab for Optical Astronomy, The Chinese Academy of Sciences, China

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Abstract. We have observed an object having strong Balmer absorption lines and blue continuum. The inference about the nuclear stellar population drawn from the line ratios is basically coincident with that drawn from the continuum color, both indicating the dominant fraction of early A type population in the nucleus. This might be expected only if there has been a very massive starburst, burst strength of $> 10\%$ at least.

Key words: Galaxies: starburst – Galaxies: stellar content – Galaxies: nuclei – Stars: formation of

1. Introduction

During our surveying IR-selected Seyferts in 1994-1995, we have observed an object having strong Balmer absorption lines, F06296+5743. It is interesting to note that its spectrum exhibits blue continuum.

Far-infrared luminous galaxies with strong Balmer absorption lines have been observed before (see, e.g. Armus, Heckman, & Miley 1989), but their continuum colors are usually very red. For example, the ratios of the continuum flux densities at rest wavelengths 6500Å and 4800Å, C65/C48, defined by Armus, Heckamn, & Miley (1989), for their observed three galaxies with Balmer absorption lines are 1.06, 1.13, and 1.45, respectively, and the equivalent widths of H β absorption line are 6.5Å, 5.2Å, and 1.2Å, respectively. As a comparison, the corresponding values for F06296+5743 are 0.77, and 8.2Å, respectively.

The anti-correlation between the equivalent widths at H β and C65/C48 may imply the effect of the burst strength on the continua, as pointed out by Bica, Alloin & Schmidt (1990). The larger the burst strength is, the bluer the continuum. Our analyses show that F06296+5743 might be a very massive starburst.

2. Observation and Data Reduction

Spectra of F06296+5743 were taken on March 4, 1995 at Beijing Astronomical Observatory (BAO) with 2.16m telescope. The TEK CCD chip (1024 \times 350) was attached to the Carl Zeiss spectrograph. A 300 lines mm⁻¹ grating was used with a 3" wide slit, providing a spectral resolution of 10.9Å FWHM over the range 3800-7600Å. One pixel corresponds to 4.7Å. Exposure time was 60 min. for object. During our exposure we had a seeing of 1.5". Flux calibration was done with spectra of Feige34 and HZ44 (Barnes & Hayes 1984). FeHeAr-spectra had been taken before and after all the object spectra for wavelength calibration.

Standard reduction procedures in IRAF were followed for bias subtraction, flat-field correction, wavelength calibration, extraction, and the flux calibration. The terrestrial absorption band of O₂ happened to be at the redshifted H α emission line, see Fig 1a. It was removed by the method described in Osterbrock et al (1990).

The spectrum in Fig 1a exhibits strong Balmer absorption lines. Since this absorption is the same at H α , H β and H γ to within 30% (Kurucz 1979), our measured equivalent widths at H β , H γ , and H δ also confirm it (see below), so we have followed the procedure suggested by Armus, Heckamn & Miley (1989) to use H β absorption line to correct the H α emission line.

It is necessary to correct all observed line fluxes for attenuation due to reddening, which has two components – foreground reddening due to dust in our Galaxy and internal reddening from dust within the source itself. In the case of F06296+5743, the later one would be difficult to settle, as the spectrum shows that H β line has no emission component so that it will not be able to obtain the observed Balmer decrement, which is needed for reducing the internal reddening. The foreground reddening could be accounted for by use of the average Galactic extinction law of Seaton (1979) and the extinction estimates towards the direction of F06296+5743 given by Burstein & Heiles (1984), which is about $A_B = 0.29$, i.e. $E(B-V) \approx 0.07$.

Send offprint requests to: J.H.Huang

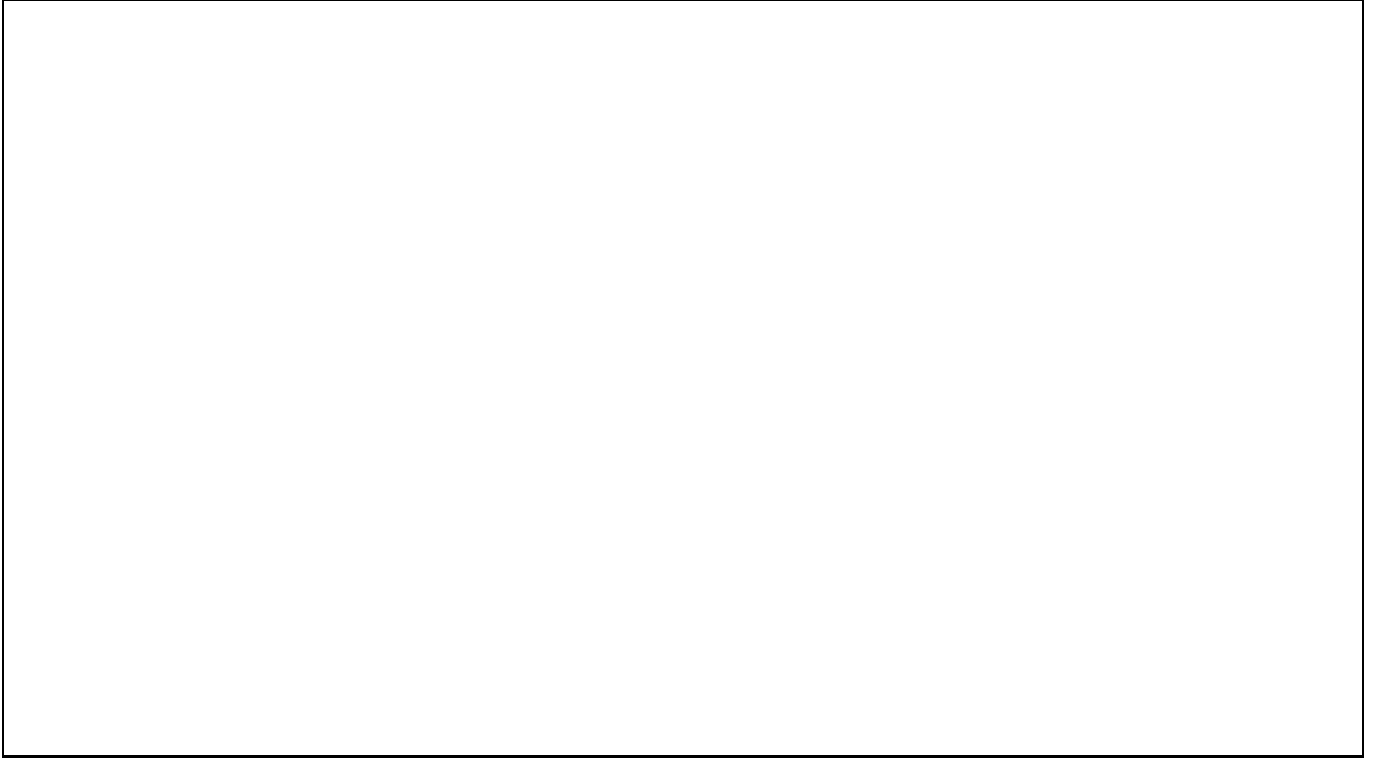


Fig. 1. Flux-calibrated spectra of F06296+5743 showing strong Balmer absorption lines, vertical scale is in $\text{ergs.cm}^{-2}\text{s}^{-1}\text{\AA}^{-1}$. (a) observed flux-calibrated spectrum, no correction was made for absorptions and instrumental-broadening; (b) final spectrum, corrected for galactic extinction, absorptions and instrumental-broadening.

The final, dereddened and absorption-corrected spectrum of F06296+5743 is shown in Fig 1b.

3. Discussion

3.1. Nuclear Physical Condition

The observed emission/absorption line intensities of F06296+5743 are tabulated in Table 1. The redshift derived from $\text{H}\beta$, $\text{H}\gamma$ and $\text{H}\delta$ lines is $\bar{z} = 0.05262$. The second column in Table 1 lists the wavelengths at the rest frame, relating to the wavelengths in the first column. At the distance of $\bar{z} = 0.05262$, 3'' slitwidth corresponds to an extension of about 3 kpc, with the Hubble constant $H_0 = 75 \text{ km/sec/Mpc}$. So, the equivalent widths and the line intensities listed in column 4 and 5 are those in the nuclear region of 3 kpc in diameter.

In the case of F06296+5743, the line ratios of $[\text{NII}]/\text{H}\alpha$ and $[\text{OI}]6300/\text{H}\alpha$ were used instead for classifying the physical condition of this source because only appears $\text{H}\alpha$ in emission, while $\text{H}\beta$ appears in absorption. In order to deblend the line of $\text{H}\alpha + [\text{NII}]\lambda\lambda 6548 + 6583$, we used the "specfit" in IRAF, an interactive procedure contributed by Gerard Kriss, in which the line-width of $\text{H}\alpha$ emission was set to about the same as the $\text{H}\beta$ line. Finally, we found that $[\text{NII}]/\text{H}\alpha = 1.07$, and $[\text{OI}]6300/\text{H}\alpha = 0.22$, meaning that F06296+5743 is an AGN-like galaxy,

according to the criteria suggested by Armus, Heckman & Miley (1989).

Comparison with the power-law photoionization models of Ferland & Netzer (1983) shows that the models do not have line ratios simultaneously consistent with both the $[\text{NII}]/\text{H}\alpha$ and the $[\text{OI}]6300/\text{H}\alpha$ observed in F06296+5743. The shock models of Binette, Dopita, & Tuohy (1985), however, can closely reproduce the relative emission line strengths seen in F06296+5743, implying that a starburst-induced, supernovae-driven superwind (see, e.g. McCarthy, Heckman & van Breugel 1987) could contribute to the energy budget of this source rather than a AGN.

3.2. Nuclear Stellar Content

As is well known that knowledge of the stellar content is basic for understanding star formation in galaxies. In the spectrum of F06296+5743, we find several absorption lines which are discriminator for stellar population, they are Balmer lines, and CaII K line (see, e.g. O'Connell 1973, Heckman 1980, Armus, Heckman & Miley 1989).

3.2.1. Balmer Lines

In older stellar population dominated by G-K giants, the absorption at $\text{H}\beta$ has been measured as $1-2\text{\AA}$ (Kennicutt

Table 1. Line Intensities of F06296+5743

λ (Å)	λ_0 (Å)	Ion	EW (Å)	I/I(H β)
3965.9	3767.7	H ₁₁	9.9	-1.269
3996.3	3796.5	H ₁₀	6.4	-0.902
4036.6	3834.8	H ₉	7.4	-0.946
4093.5	3888.9	H ζ	9.6	-1.376
4139.7	3932.8	CaII K	4.0	-0.562
4178.2	3969.3	H ϵ +CaII H	9.1	-1.301
4317.9	4102.0	H δ	8.3	-1.022
4568.6	4340.2	H γ	8.2	-1.064
5117.4	4861.6	H β	8.2	-1.00
5445.1	5172.9	Mg I b	2.5	-0.304
6200.8	5890.8	Na I D	2.8	-0.296
6629.9	6298.4	[O I]	-2.8	0.265
6891.9	6547.4	[N II]	-4.4	0.440
6907.7	6562.4	H α	-12.4	1.227
6930.5	6584.0	[N II]	-13.3	1.322
7067.7	6714.4	[S II]	-3.4	0.290
7084.4	6730.2	[S II]	-4.7	0.391

1983). The Balmer equivalent widths in A types, which are the largest ones in various type of stars, typically have 4Å at H β as giants, and ~ 8 Å at H β as dwarfs (O’Connell 1973). The measured Balmer equivalent widths of F06296+5743 at H β , H γ , and H δ , see column 4 of Table 1, are 8.2, 8.2 and 8.3Å, respectively, indicating dominant population of A dwarfs in the nuclear region of F06296+5743.

The width of Balmer lines provides additional evidence for the identification of a young, and probable dwarf, component in the nucleus of this source. It is known that pressure broadening of the Balmer lines is greatest in dwarfs. For F06296+5743, the H δ ’s width at 20% of the maximum negative intensity is about 28Å, corrected for the instrumental profile. This value fits the correlation between the equivalent width of H δ and its width well (see, e.g. Heckman 1980), suggesting again that the Balmer lines come primarily from young, and probable dwarfs, stars rather than a hotter giants or horizontal branch.

3.2.2. CaII K Line

The K line of $\lambda 3933$ is known to be a useful indicator for spectral types of A and later. The criteria for HD spectral classification in A type stars (Lang 1980) are as follows: CaII K=0.4 H δ for A2 type; K=0.8 H δ for A3; K > H δ for A5 type. The measured intensity of CaII K line in F06296+5743, see column 5 of Table 1, is about half of that of H δ , suggesting the existence of a substantial content of A2-A3 stars in the nucleus.

Vacca & Conti (1992) have estimated strength of interstellar CaII K feature, which is not greater than 0.15Å. Thus, the observed CaII K line in F06296+5743 is primarily of stellar origin.

Besides, the K line index (O’Connell 1973) derived from the spectrum of this source is about 0.25, a value relevant to A3-A5 type stars. This is consistent with the inference from comparison of CaII K with H δ that the dominant population in the nuclear region might be A2-A3 stars.

3.2.3. "V/R" and Continuum Colors

French (1980) has introduced continuum colors, B’-V’ and V’-R’, defined at 4200Å(B’), 5300Å(V’) and 7000Å(R’) respectively, to set the dominant sources for continuum energy distribution of extragalactic objects. According to his definition, we derived the continuum colors of F06296+5743, B’-V’=-0.20, V’-R’=-0.32. Compared with the colors for several main-sequence stars provided by French (1980), we found that the colors of F06296+5743 is somewhat later than A0 (B’-V’=-0.25, V’-R’=-0.33), and earlier than A5 (B’-V’=-0.15, V’-R’=-0.22).

The continuum index V/R has been used for characterizing energy distribution of galaxies (O’Connell 1973). It is also found of great use to set the dominant contribution to the spectral energy budget of F06296+5743. The observed dereddened V/R of our source was obtained to be -0.32. The data for F06296+5743 did not extend to 7400Å in the object’s frame, and the continuum had to be extrapolated about 200Å to derive R’. But the errors introduced by this extrapolation may be small. The observed V/R will not be larger than -0.29 in any case.

Due to the tight correlation between the V/R continuum index and the V-R broad-band color below V/R = +0.15 (O’Connell 1973), we could apply the K-correction, $K_V - K_R$, by Whitford (1971) to V/R. Its value is about 0.045 for $z=0.05262$. The final, dereddened V/R would be roughly in between -0.29 and -0.37, a value corresponding to B8-A0 energy distribution. (O’Connell 1973).

In summary, the spectral analyses described in section 3.2.1 through section 3.2.3 come to the more or less same conclusion that the dominant population of F06296+5743 might be early A type stars, A2/A3 most likely.

3.2.4. Age of Starburst

The dereddened broad-band color V-R of F06296+5743 could be roughly obtained from the tight correlation between the continuum index V/R and the broad-band color V-R below V/R = +0.15 (O’Connell 1973), as we pointed out in sec. 3.2.

The V-R derived this way is in between -0.03 and +0.11 at most, corresponding to V/R of -0.29 - -0.37. By comparison with the predictions of V-R from Leitherer & Heckman (1995) for a continuous star-formation rate, the burst age would be $< 7 \times 10^7$ yr in any case.

The correction for the intrinsic reddening, if we could do that, would make V-R bluer than the above values.

So, it would be safe for us to estimate the age of starburst to be $< 10^8$ yr.

4. Conclusion

It is interesting to find that despite the very strong internal reddening of F06296+5743, inferred from its high far-infrared luminosity of $\log L_{\text{FIR}} = 10.69$ with Hubble constant of 75km/sec/Mpc, the dominant nuclear stellar population of early type of A stars deduced from the continuum color, V/R or $V-R$, is basically matching what derived from the Balmer line intensities and line ratios. This would be a strong evidence to indicate that the contribution from old population within the galactic bulge has been substantially suppressed even at an age of burst $\sim 7 \times 10^7$ yr.

We have noticed that in various empirical models discussed by Bica, Alloin, & Schmidt (1990), the model value of the continuum color, $V-R$, is 0.38 for 10% mass burst at age of $7 \times 10^7 - 2 \times 10^8$ yr. It is much redder than the dereddened color of 0.11 for F06296+5743. We have also noticed, however, that the predicted continuum colors, $V-R$, are getting bluer with increasing of the burst strength in models presented by Bica, Alloin, & Schmidt (1990). It would be very reasonably and naively then to suspect that the situation showing in F06296+5743 might be a result from a very massive starburst, more than 10% burst strength at least.

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